MULTIMEDIA UNIVERSITY ™

STUDENT ID NO

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# MULTIMEDIA UNIVERSITY

# FINAL EXAMINATION

**TRIMESTER 2 , 2022/2023**

## ERT3016 – ROBOTICS
**(RE)**

06 JULY 2023
9.00 a.m. – 11.00 a.m.
(2 Hours)

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**INSTRUCTIONS TO STUDENT**

1. This Question paper consists of **6 pages** including cover page with **4 Questions** only.

2. Attempt **ALL** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please write all your answers in the Answer Booklet provided.

## QUESTION 1

**(a)** A point P in space is defined as $[\mathbf{p}]^{M} = [\ -4,\ 8,\ 6]^{T}$ relative to a mobile frame M, which is initially coincide with the reference frame F.

(i) Apply the following transformations and find the homogeneous transformation matrix, $\boldsymbol{T}$.

- First, Translate 2 units along $\mathbf{m}^1$ ,5 units along $\mathbf{m}^2$, and -10 units along $\mathbf{m}^3$.
- Then, Rotate 90° about $\mathbf{f}^2$
- Finally, rotate -90° about $\mathbf{f}^3$

**[11 marks]**

(ii) Find $[\boldsymbol{p}]^{F}$. **[4 marks]**

**(b)** In the 2-DOF robot, the transformation matrix $\mathbf{T}_{\mathbf{base}}^{\mathbf{tool}}$ is given in symbolic form, as well as in numerical form for a specific location. The length of each link $l_1$ and $l_2$ is 1 ft.
Calculate the values of $\theta_1$ and $\theta_2$ for the given location.

$$T_{base}^{tool} = T_0^2 = \begin{bmatrix} C_{12} & -S_{12} & 0 & l_2C_{12} + l_1C_1 \\ S_{12} & C_{12} & 0 & l_2S_{12} + l_1S_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} -0.2924 & -0.9563 & 0 & 0.6978 \\ 0.9563 & -0.2924 & 0 & 0.8172 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where, $C1=\cos q_1$; $S1=\sin q_1$; $C2=\cos q_2$; $S2=\sin q_2$.

**[10 marks]**

**Continued...**

## QUESTION 2

The 3-DOF (RPR) manipulator arm is shown in **Figure Q2.**

**(a)** Determine the frame assignment. **[6 marks]**

**(b)** Determine the joint link parameter. **[6 marks]**

**(c)** Obtain the overall homogeneous transformation matrix. **[8 marks]**

**(d)** Calculate the rotation matrix that describes the orientation of the tool relative to the base frame for $q = [30° \; 20 \; 60°]^T$. **[5 marks]**

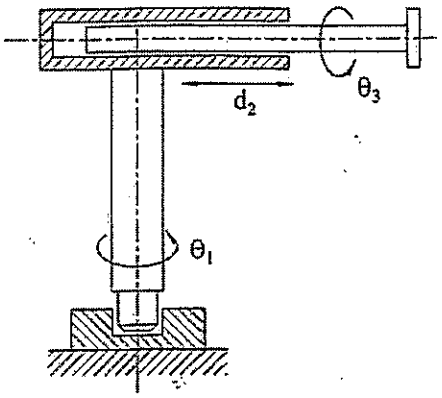


**Figure Q2**

## QUESTION 3

**(a)** One joint of an articulated robot shall go from initial angle 20° to a final angle of 80° in 4.5 seconds. The robot starts from rest, but is supposed to have a final velocity of 5 degree/sec.

(i) Calculate the coefficients for a third order polynomial joint space trajectory. **[8 marks]**

(ii) Sketch the plot for the joint angles, velocities, and accelerations for the times t = 0 sec, 1.5 sec, 3 sec and 4.5 sec. **[12 marks]**

**(b)** Explain briefly lift off point and set down point. **[5 marks]**

**Continued...**

## QUESTION 4

**(a)** The hand frame of a robot with five degrees of freedom ($T_6$), its numerical Jacobian for this instant ($J$) and a set of different motions are given. The robot has a 2RP2R configuration. It is assumed that the robot can only rotate about the x- and y- axes. Find the new location of the hand after the differential motion.

**[15 marks]**

$$T_6 = \begin{bmatrix} 1 & 0 & 0 & 5 \\ 0 & 0 & -1 & 3 \\ 0 & 1 & 0 & 2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$J = \begin{bmatrix} 3 & 0 & 0 & 0 & 0 \\ -2 & 0 & 1 & 0 & 0 \\ 0 & 4 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ -1 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} d\theta_1 \\ d\theta_2 \\ ds_1 \\ d\theta_4 \\ d\theta_5 \end{bmatrix} = \begin{bmatrix} 0.1 \\ -0.1 \\ 0.05 \\ 0.1 \\ 0 \end{bmatrix}$$

**(b)** For a spherical robot, the three components of the velocity of hand frame for a corresponding location is given by:

$$\begin{bmatrix} \boldsymbol{dp_x} \\ \boldsymbol{dp_y} \\ \boldsymbol{dp_z} \end{bmatrix} = \begin{bmatrix} \boldsymbol{\sin\beta\, cos\,\gamma} & \boldsymbol{r\, cos\,\beta\, cos\,\gamma} & \boldsymbol{-r\sin\beta\sin\gamma} \\ \boldsymbol{sin\beta\sin\gamma} & \boldsymbol{r\cos\beta\, sin\,\gamma} & \boldsymbol{r\, sin\,\beta\, sin\,\gamma} \\ \boldsymbol{cos\,\beta} & \boldsymbol{-r\sin\beta} & \boldsymbol{0} \end{bmatrix} \bullet \begin{bmatrix} \boldsymbol{dr} \\ \boldsymbol{d\beta} \\ \boldsymbol{d\gamma} \end{bmatrix}$$

where $\begin{bmatrix} \sin\beta\, cos\,\gamma & r\, cos\,\beta\, cos\,\gamma & -r\sin\beta\sin\gamma \\ sin\beta\sin\gamma & r\cos\beta\, sin\,\gamma & r\, sin\,\beta\, sin\,\gamma \\ cos\,\beta & -r\sin\beta & 0 \end{bmatrix}$ is the Jacobian.

Calculate the required three joint velocities that will generate the following hand frame velocity:

$\dot{x} = 5\ in/sec$
$\dot{y} = 9\ in\ /sec$
$\dot{z} = 6\ in/\ sec$
$\beta = 60°$
$\gamma = 30°$
$r = 20$ in

**[10 marks]**

**Continued...**

## Appendix

Procedure to DH-Parameter

1. Number the joints from 1 to $n$ starting at the base and ending with the tool yaw, pitch and roll, in that order.
2. Assign a right-handed orthonormal coordinate frame $L_0$ to the robot base, making sure that $z^0$ aligns with the axis of joint 1. Set $k=1$.
3. Align $z^k$ with the axis of joint $k+1$.
4. Locate the origin of $L_k$ at the intersection of the $z^k$ and $z^{k-1}$ axes. If they do not intersect, use the intersection of $z^k$ with a common normal between $z^k$ and $z^{k-1}$.
5. Select $x^k$ to be orthogonal to both $z^k$ and $z^{k-1}$. If $z^k$ and $z^{k-1}$ are parallel, point $x^k$ away from $z^{k-1}$.
6. Select $y^k$ to form right-handed orthonormal coordinate frame $L_k$ and set $k=k+1$. If $k<n$, go to step 3; else continue.
7. Set the origin of $L_n$ at the tool tip. Align $z^n$ with the approach vector, $y^n$ with the sliding vector

   and $x^n$ with the normal vector of the tool. Set $k=1$.
8. Locate point $b^k$ at the intersection of the $x^k$ and $z^{k-1}$ axes. If they do not intersect, use the intersection of $x^k$ with a common normal between $x^k$ and $z^{k-1}$.
9. Compute $\theta_k$ as the angle of rotation from $x^{k-1}$ to $x^k$ measured about $z^{k-1}$.
10. Compute $d_k$ as the distance from the origin of frame $L_{k-1}$ to point $b^k$ measured along $z^{k-1}$.
11. Compute $a_k$ as the distance from the point $b^k$ to the origin of frame $L_k$ measured along $x^k$.
12. Compute $\alpha_k$ as the angle of rotation from $z^{k-1}$ to $z^k$ measured about $x^k$.
13. Set $k=k+1$. If $k \leq n$, go to step 8; else stop.

Generic DH-Transformation Matrix

$$T_{k-1}^{k} = \begin{bmatrix} C\theta_k & -S\theta_k C\alpha_k & S\theta_k S\alpha_k & a_k C\theta_k \\ S\theta_k & C\theta_k C\alpha_k & -C\theta_k S\alpha_k & a_k S\theta_k \\ 0 & S\alpha_k & C\alpha_k & d_k \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Fundamental Rotation Matrix

$$R_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta & -sin\theta \\ 0 & sin\theta & cos\theta \end{bmatrix} \quad R_2 = \begin{bmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ -sin\theta & 0 & cos\theta \end{bmatrix} \quad R_3 = \begin{bmatrix} cos\theta & -sin\theta & 0 \\ sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

**Continued...**

Homogenous Transformation Matrix

$$T=\begin{bmatrix} \overbrace{R}^{\text{rotation}} & \overbrace{p}^{\text{position}} \\ \underbrace{\eta^T}_{\text{perspective}} & \underbrace{\alpha}_{\text{scale}} \end{bmatrix}$$

Fundamental Homogenous Rotation and Translation Matrix

$$Rot(\phi,k)=\begin{bmatrix} R_k(\phi) & \begin{matrix}0\\0\\0\end{matrix} \\ \begin{matrix}0 & 0 & 0\end{matrix} & 1 \end{bmatrix} \quad 1 \le k \le 3$$

$$Trans(p)=\begin{bmatrix} 1 & 0 & 0 & p_1 \\ 0 & 1 & 0 & p_2 \\ 0 & 0 & 1 & p_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Inverse Homogenous Transformation Matrix

$$T^{-1}=\begin{bmatrix} R^T & -R^T p \\ 0\ \ 0\ \ 0 & 1 \end{bmatrix}$$

**End of Paper**